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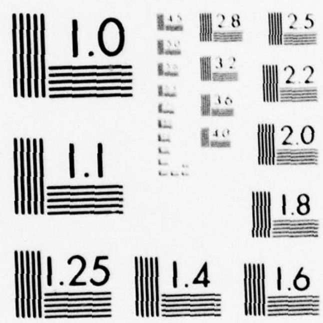

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3 LEVEL II

AREA CORRELATION TECHNIQUES IN REMOTELY PILOTED VEHICLE GUIDANCE

C. Munteanu

G. Trottier

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6 Area Correlation Techniques

In Remotely Piloted Vehicle Guidance,

by

10 C./Munteanu ~~and~~ G./Trottier

11 Mar 79

12 32 p.

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RESUME

On applique les techniques de la corrélation de surface au guidage en phases intermédiaire et terminale d'un avion sans pilote (télécommandé) effectuant une mission d'attaque. En phase intermédiaire, le cap est corrigé par la reconnaissance de points de référence échelonnés le long d'une route programmée à l'avance. En phase terminale, lors du bombardement, la cible est acquise par télécommande et la poursuite est effectuée de façon autonome au moyen d'une technique de compensation du grandissement apparent de la cible. Cette technique utilise un zoom.

Ce rapport porte également sur une simulation des deux phases du guidage et démontre comment un corrélateur d'image basé sur l'algorithme de détection séquentiel de similarité peut s'y appliquer. (NC)

ABSTRACT

Area correlation techniques are applied to the long-range remotely piloted vehicle (RPV) attack mission in both mid-course and terminal guidance phases. The mid-course guidance consists of a set of navigation fixes at waypoints along a preprogrammed route. The terminal guidance for weapon delivery incorporates a technique of compensation for magnification during range closure via a zoom lens. This report also presents simulations of both phases of guidance, using the sequential similarity detection algorithm as the image correlator. (U)

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1.0 INTRODUCTION

Area correlation is a target tracking technique involving the detection of a reference image of the target within the incoming live scenery acquired by an imaging sensor. The location within the search scene that bears the greatest similarity to the reference image determines the position of the target. In a snap-and-go missile system, where the target is in sight, the reference image is taken from the imaging sensor and stored just prior to launch. Alternatively, for a stand-off mission, the reference image can be prepared off-line from available intelligence imagery.

The area correlation techniques studied and developed at DREV have a primary application to terminal guidance. This report presents the extension of these techniques to the long-range guidance of remotely piloted vehicles (RPVs).

In view of electronic warfare (EW) deployment and operational considerations, manual steering of a long-range RPV by an operator at a remote location is not desirable. A preferred technique requires the RPV to fly a preprogrammed course to the mission area using self-contained navigation. However, with inertial navigation systems (INS) or Doppler systems, position accuracies of several tens of meters over relatively long flight times cannot be achieved without external aid. At typically required stand-off ranges of 800 km (500 mi) or greater, and with RPV speeds of 800 km/h, attack missions would involve flight times of one hour or more. Currently available inertial platforms of reasonable cost have drift rates of the order of 0.8 km

(0.5 mi) per hour of flight. The navigation error at the end of a one-hour mission may therefore be as great as 800 m. Errors of this magnitude do not permit effective attack against hardened military targets. Navigation updating performed by area correlation matching over predetermined areas is an adjunct that may achieve the stated navigation accuracy.

In an attack mission, area correlation tracking is also applicable to the weapon delivery sequence. While entering the mission area, the data links between the RPV and the control station can be re-established and images of the live scenery transmitted back to the control station. The operator can then isolate a target of interest, shut off the video link and command the RPV to initiate and carry out weapon delivery using its own tracking system. If the mission is completely predetermined, then targeting can be made automatic by adding a target reference to the set of mid-course references.

Figure 1 illustrates a typical RPV long-range attack mission which includes both applications of area correlation: that of obtaining fixes to correct for inertial navigation errors (drifts during long-range navigation) and that of target tracking during the weapon delivery. Simulations representing both mid-course and terminal phases of this mission are presented in this report. Although there are a number of successful image-matching algorithms, this study is restricted to the relatively newer sequential similarity detection algorithm (SSDA) (Refs. 1, 2). A very attractive feature of this algorithm is its high speed.

This work was performed at DREV during 1976-1977 under PCN 21J03 "Imaging Seekers". The content of this report has previously appeared in a paper entitled "Applications of Area Correlation Techniques to RPV Guidance" presented to TTCP HTP-1 (Aerial Targets and Drones) at the 20th Meeting held at DREV, 23 September 1977.

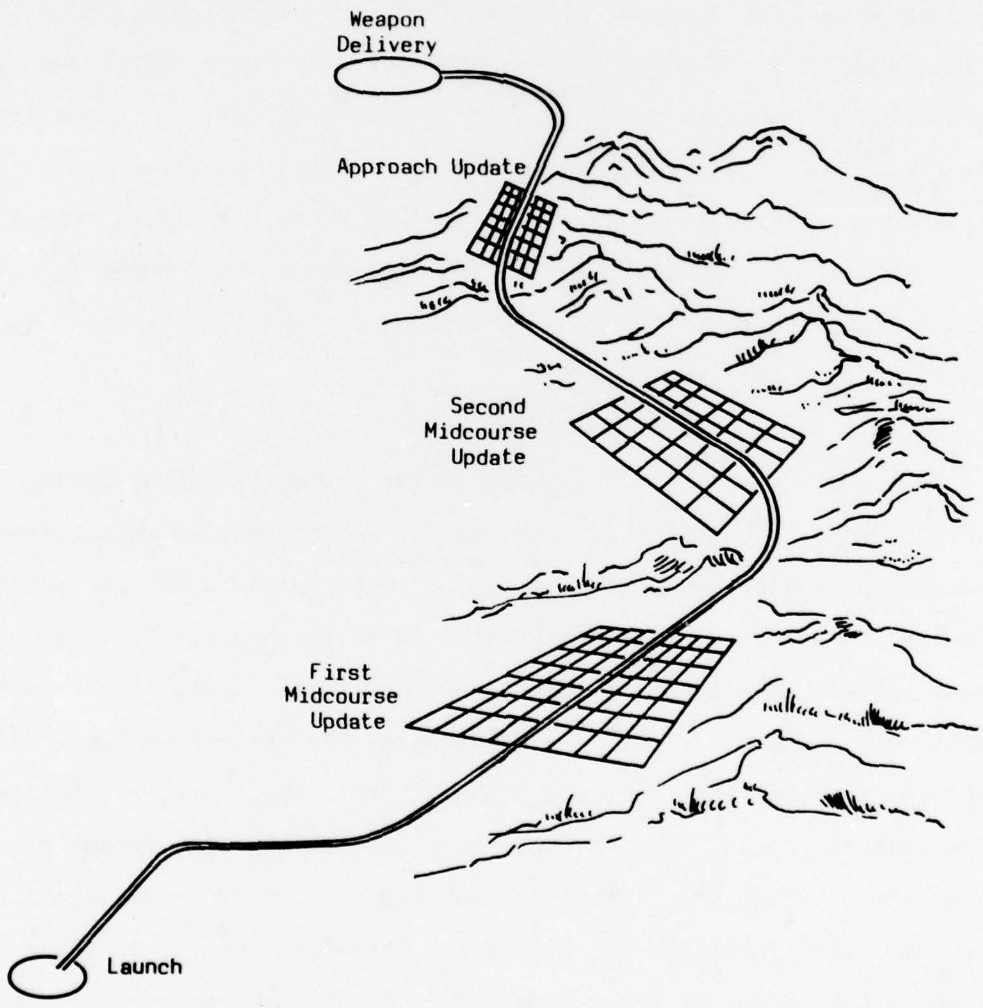


FIGURE 1 - Long-range RPV attack mission

2.0 THE SEQUENTIAL SIMILARITY DETECTION ALGORITHM

An image-matching algorithm that has been studied in detail at DREV is the sequential similarity detection algorithm (SSDA). There are several reasons for interest in this algorithm. First, the SSDA is very fast compared to conventional cross-correlation techniques, both in quantity and type of computation. That is, many fewer operations are performed and the operations are simpler, being subtractions rather than multiplications. The second reason is that the SSDA performs well in terms of output correlation peak-to-background ratio. Thirdly, the SSDA has an attractively simple hardware implementation. All these factors make this algorithm very promising for use as an onboard real-time image correlator.

The intuitive basis of the SSDA is the proposition that making a confident decision that two pictures do not match requires considerably less work than making a confident decision that two pictures do match. The actual operation of the algorithm is quite simple. Pictures are compared element by element in non-repeating random order (so as to generate new information at each step). The algorithm computes a cumulative sum of the absolute values of the errors between picture-element pairs, and at every step subjects the cumulative error to a threshold. When the threshold is exceeded, the comparison is halted and the function of similarity between the two pictures is recorded as the number of steps required to cross the threshold. When pictures are similar, this similarity function is large since many elements will be compared before reaching the threshold. Conversely, the similarity function will be small when pictures are dissimilar.

Moreover, when pictures are dissimilar, a relatively small amount of computation is performed since comparison terminates early. Since the vast majority of correlation points are points of image dissimilarity, the result is a drastic overall reduction in computation.

Figure 2 illustrates the typical operation of the SSDA. Note that the threshold is not a constant throughout the image comparison. This is so that comparison of dissimilar pictures terminates as early as possible, but comparison of similar pictures is allowed to proceed fully. Curve D is a cumulative error curve for the case where pictures are dissimilar. It is seen that the threshold is hit at an early stage, resulting in a small value for the similarity function and also in a small amount of computation expended. Curve S corresponds to the case where pictures are similar. Here the comparison proceeds to a much later stage, giving a high value of similarity function.

Although the SSDA is a simple algorithm, analysis is not simple because of its highly nonlinear operation. For binary pictures, it is possible to predict the performance of the SSDA for any given threshold sequence (Ref. 2). But determining analytically the threshold that optimizes the SSDA's performance remains a formidable problem. There are two heuristically derived threshold sequences, however, that work well although neither was derived to optimize any performance criterion (Ref. 1). One of these is called the mean-deviation threshold and is given by

$$T(k) = k\,\bar{N} + \sqrt{k}\,\sigma \qquad [1]$$

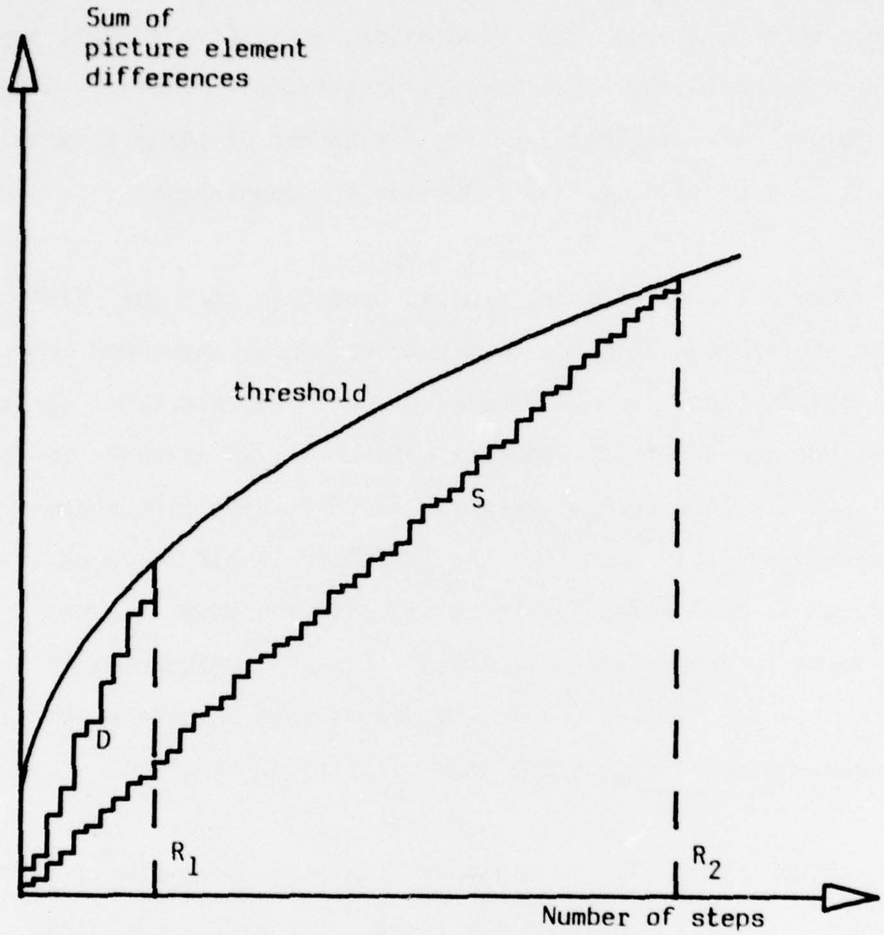


FIGURE 2 - Typical operation of the SSDA. When images are dissimilar (D), the cumulative error grows rapidly, giving a low value of similarity. With similar images (S), the error grows slowly and the similarity function is large.

where $\overline{N}$ is the mean of the absolute value of the noise, and σ is a deviation to be accounted for. This threshold provides a reasonable upper bound for the cumulative error curve obtained at image registration (match-up). The other threshold sequence is called the equiprobable threshold and is derived by assigning at registration an equal probability, at any step, that the threshold will be crossed, given that no threshold crossing occurred before.

These thresholds are noise-level dependent and the tracking system would be required to store a set of these, and use whichever it finds appropriate. In Ref. 2, both types of threshold have been rederived for binary pictures and then analysed and tested.

Figures 3 and 4 show the application of the binary SSDA to an aerial infrared photograph of a highway scene. (This example is taken from Ref. 2). In Figure 3, the inner and outer white squares on the highway photo define respectively a 16 X 16 element target image and a 48 X 48 element search scene. In Figure 4, the four correlograms (similarity functions) produced by the SSDA correspond to the use of both types of threshold sequence (mean-deviation and equiprobable) at two image signal-to-noise ratios (ISNR), 25 db and 10 db. Appropriate levels of noise had been digitally added to the search scene prior to correlation.

The resulting correlation signal-to-noise ratios (CSNR), or peak-to-background ratios, are close to those predicted by the analysis of Ref. 2. Although there does not appear to be a great deal of difference between the performances of the two threshold sequences,

there is a trend (also predicted in Ref. 2) that at low noise levels the mean-deviation threshold performs somewhat better than the equiprobable threshold, while at high noise levels, the equiprobable threshold is superior.

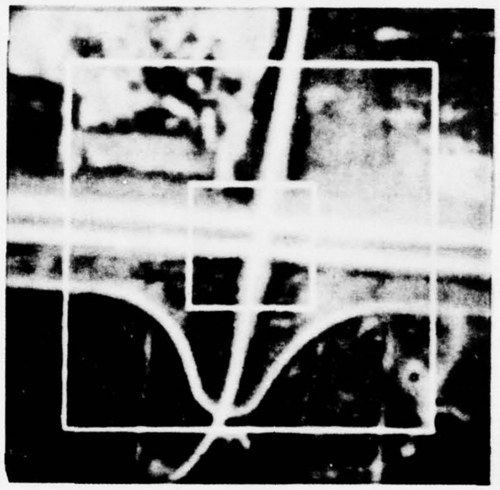
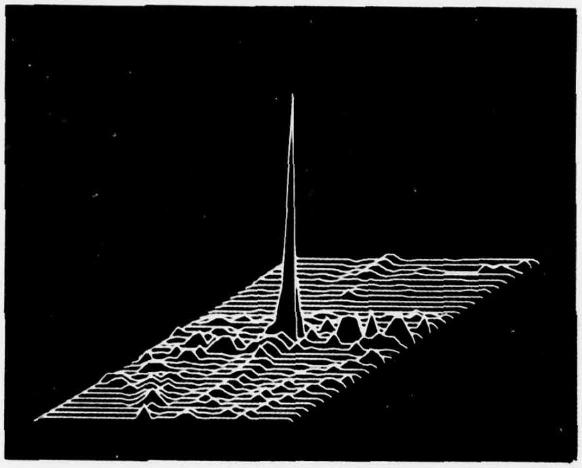
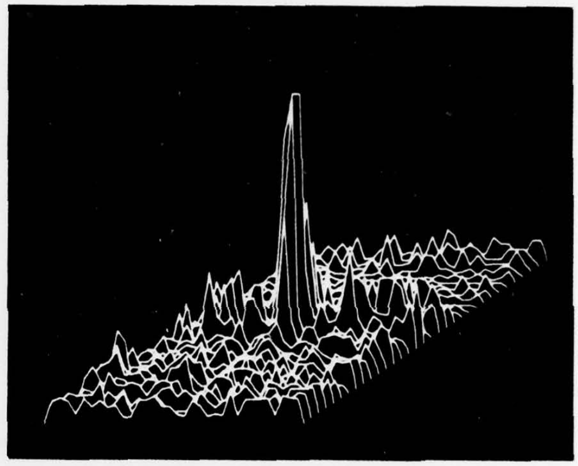


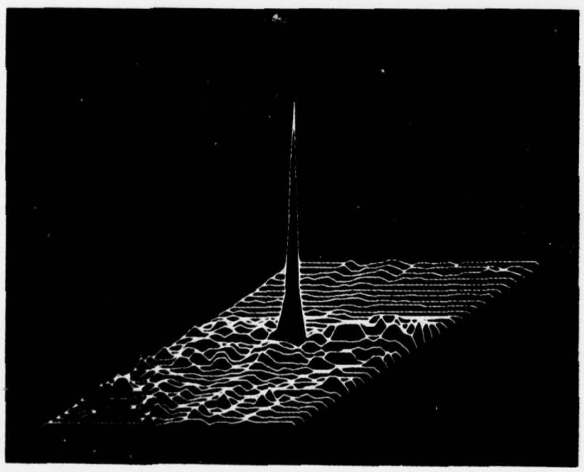
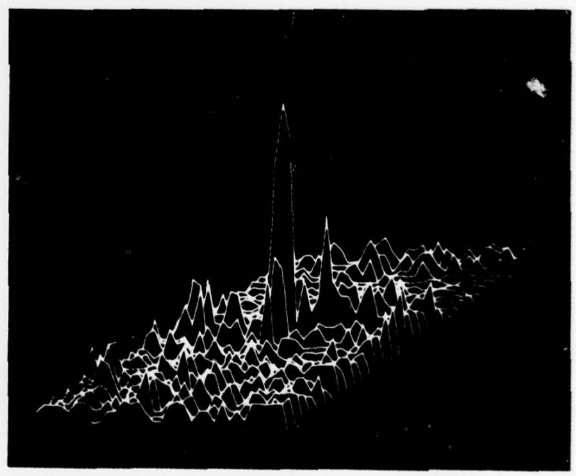
FIGURE 3 - Aerial infrared highway photograph. Reference image and search scene are outlined by white squares.

ISNR = 25.0 db
CSNR = 32.4 db

Mean-Deviation
Threshold

ISNR = 10.0 db
CSNR = 20.8 db

ISNR = 25.0 db
CSNR = 29.2 db

Equiprobable
Threshold

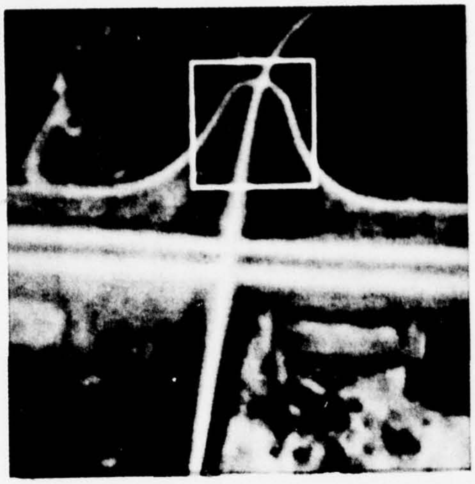
ISNR = 10.0 db
CSNR = 21.2 db

FIGURE 4 - Application of SSDA to the highway photograph

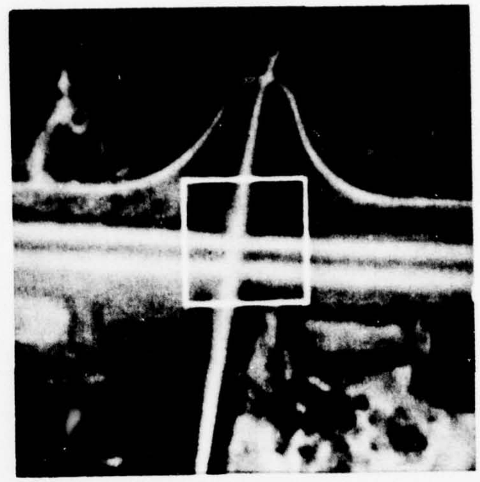
3.0 MID-COURSE GUIDANCE

At DREV, the study of area correlation has centered mainly on terminal guidance. However, the SSDA has been tested for application to the mid-course guidance of an RPV. This guidance consists of a set of navigation fixes at waypoints along a preprogrammed route. Unlike a target tracker, a waypoint guidance system cannot assume that the reference image it is looking for actually lies within its field of view. Therefore it must not only look for the best match, but must also decide whether or not that match is a true match and not just the best one in a scene that does not actually contain the reference. This decision can be made simply by thresholding the similarity function. It is necessary also, however, to limit the highest threshold sequence available to the SSDA processor, since the similarity function can always be made to cross the decision threshold by using a high enough threshold sequence.

Figure 5 shows the reference image data used in the SSDA waypoint guidance test. Figures 5(a) and (b) show a reference image of the highway in which two different targets have been picked out to serve as waypoint (mid-course) references. The target outlined in Figure 5(a) will be referred to as the service road target, while that of Figure 5(b) will be called the intersection target. These targets are 32 X 32 element segments of 128 X 128 element images. Figures 5(c) and 5(d) are binary versions of Figures 5(a) and 5(b) respectively. The binarization thresholds were determined by the mean values of 32 X 128 element image segments containing the targets at the center. The guidance system will also binarize the search scenery according to the mean of the full width

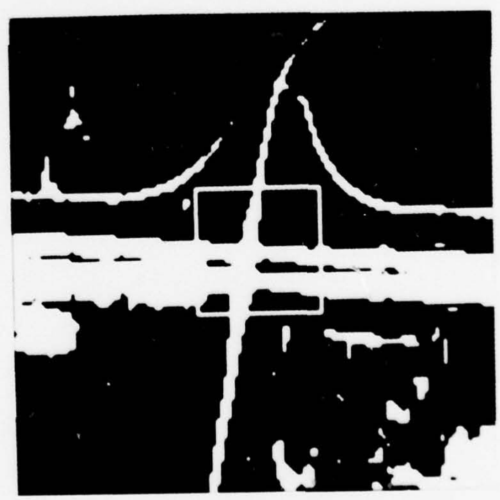


(a) Service road target



(b) Intersection target

(c) Binary version of service road target



(d) Binary version of intersection target

FIGURE 5 - Reference imagery for waypoint guidance simulation

of the search scene. This procedure desensitizes the binarization threshold to lateral RPV position errors.

Figure 6 shows the search scene, representing what an RPV might "see" as it flies over an expected waypoint area. This search image is, in fact, a degraded version of the reference image (Figure 5), being an entirely different digitization of the same negative. Some phosphor burn marks due to the flying spot scanner used in preparing the search scene are visible. Also present are differences in scale, orientation, and contrast. All these effects can be considered to be simulating errors in the preparation of the reference imagery as well as differences in weather conditions between mission preparation and execution.

In the simulation, the RPV flies in the direction indicated in Figure 6. When instructed by the onboard inertial navigation system that it is approaching a waypoint, the RPV begins to compute and store a series of one-dimensional correlograms by using the binary SSDA. The one-dimensional correlograms correspond to the reference image being scanned across the search scene in a direction perpendicular to the direction of flight, as shown in Figure 7. A detection hit is scored when an SSDA comparison within a scan proceeds to completion with a mean-deviation threshold sequence corresponding to a pre-assigned minimum image signal-to-noise ratio (10 db for this test). Whenever a scan produces a hit, the one-dimensional correlogram is recomputed with lower threshold sequences associated with higher and higher signal-to-noise ratios. The increments in signal-to-noise ratio are steps of 2.5 db. The correlograms are recomputed until further lowering

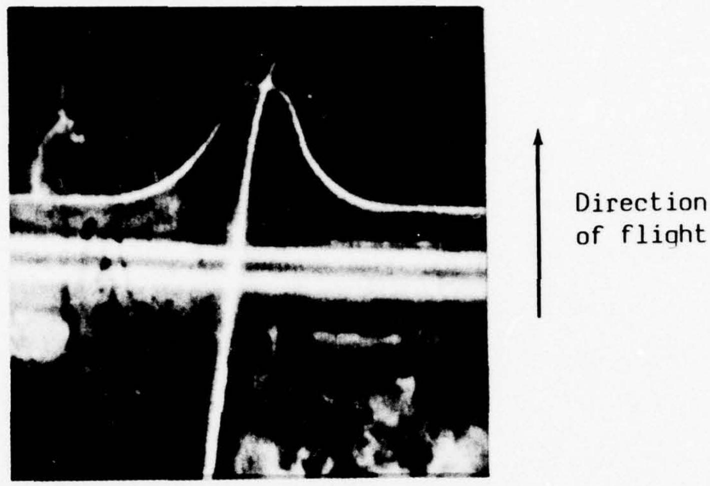


FIGURE 6 - Search scene for waypoint guidance simulation

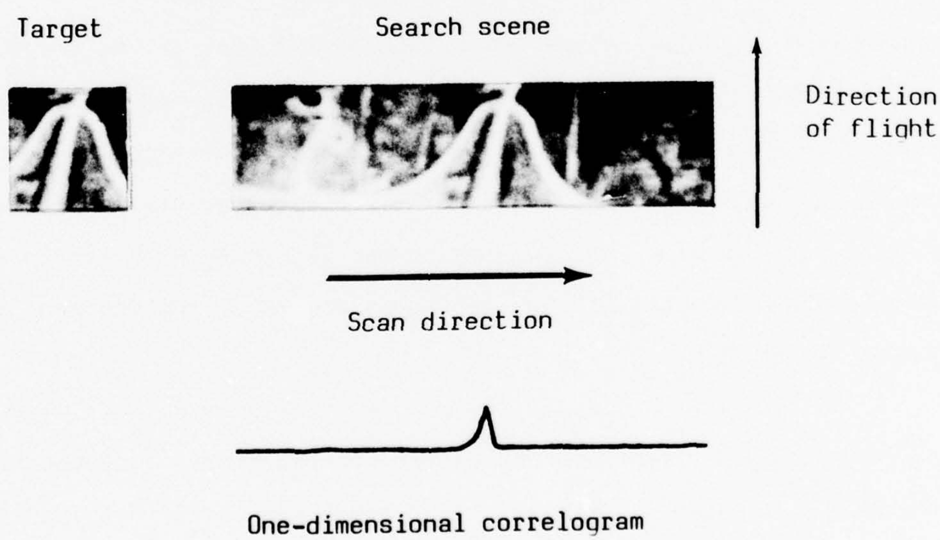


FIGURE 7 - Scan for one-dimensional correlogram

of the threshold would no longer allow the SSDA comparison to proceed to completion.

When the RPV is confident that it has overflown the waypoint, based on inertial navigation data, correlation on that waypoint is terminated. The RPV chooses as the correct match-point the hit within the one-dimensional correlogram that was obtained with the lowest threshold sequence (highest signal-to-noise ratio). The location of this match-point is used to perform a precision update of the less accurate inertial navigation system and the RPV flies on toward the next waypoint.

Figure 8 shows the set of correlograms obtained for the service road target. Scan numbers are marked on the left of the correlograms and the associated signal-to-noise ratios are indicated on the right. Figure 8(a) shows every fourth scan. Scans neighboring the match-point scan are shown in Figure 8(b). No difficulty was experienced in detecting the service road in scan number 72, using a threshold sequence corresponding to a 20 db signal-to-noise ratio. No problems of false matches occurred.

In Figure 9 is shown the set of correlograms computed for the intersection target. Again, the target was easily detected, in scan number 40 with a signal-to-noise ratio of 25 db. A potential false match problem was evident, however, in scan number 38. Several complete SSDA comparisons occurred on the far right side of scan number 38 with a threshold sequence corresponding to a 15 db signal-to-noise ratio. Although detection of the correct match remained quite safe (at 25 db),

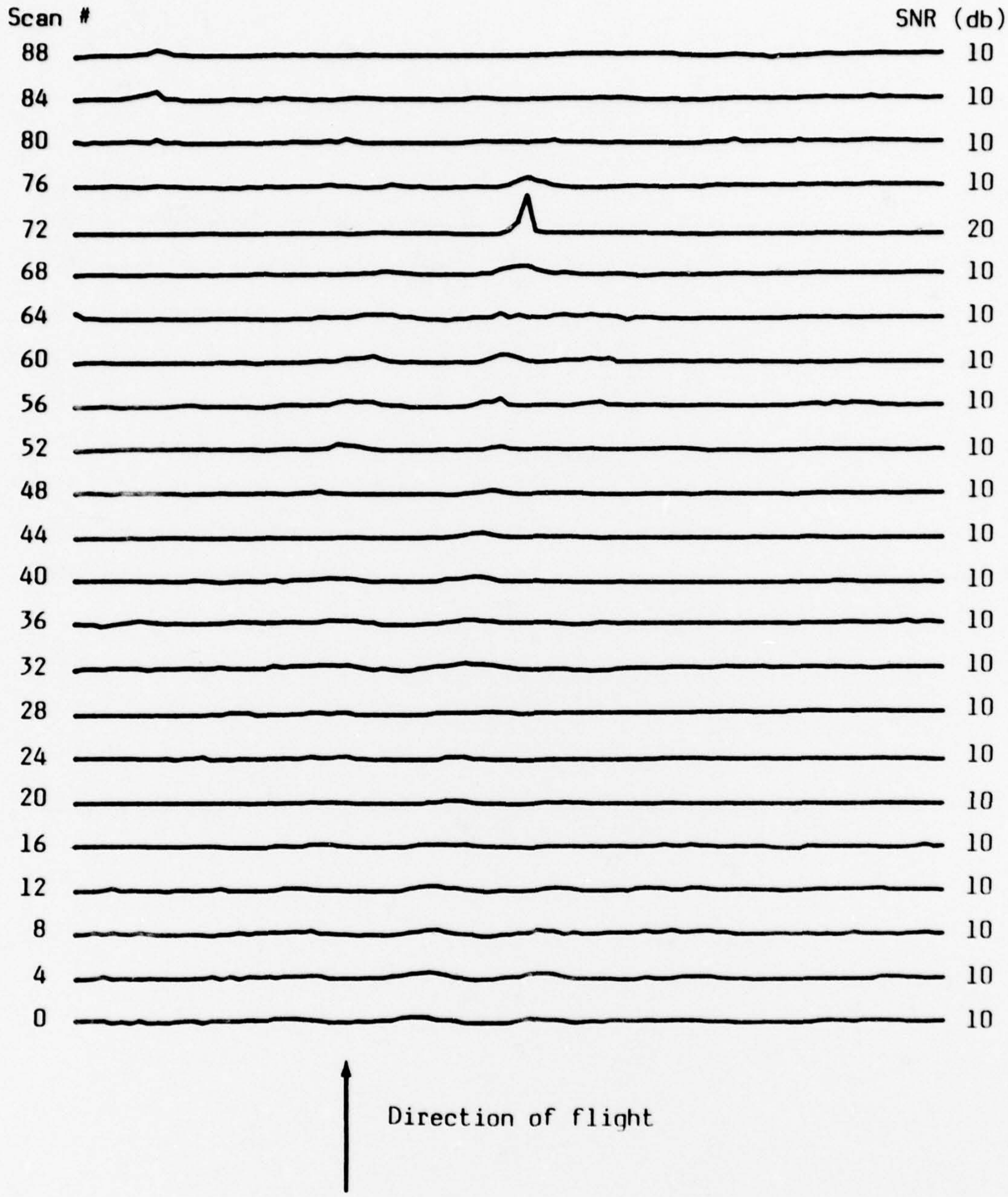


FIGURE 8(a) - One-dimensional correlograms for service road reference (every fourth scan)

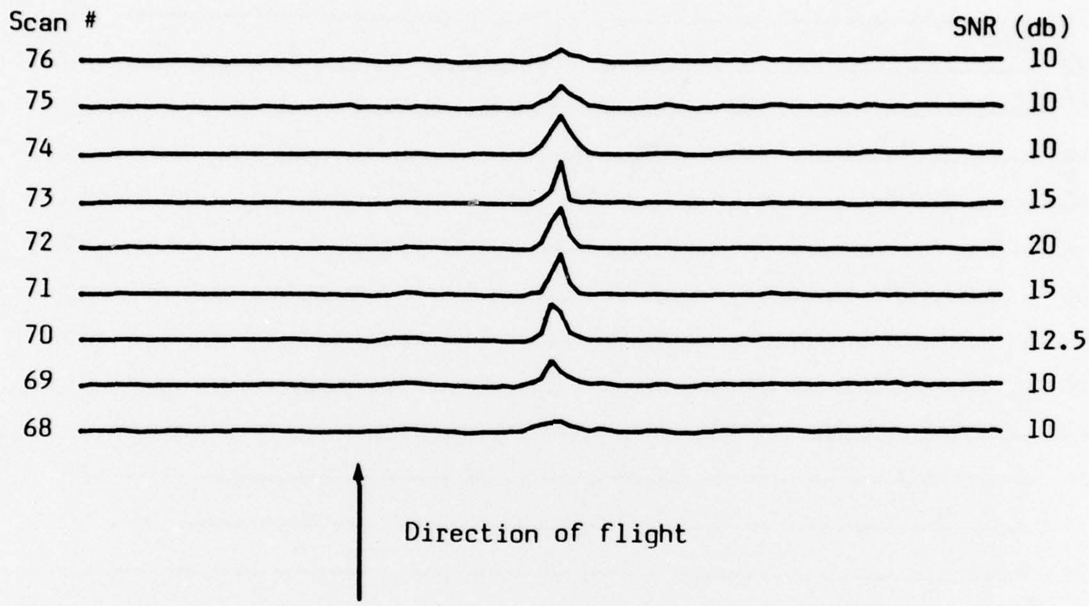


FIGURE 8(b) - One-dimensional correlograms for service road reference (detail of (a))

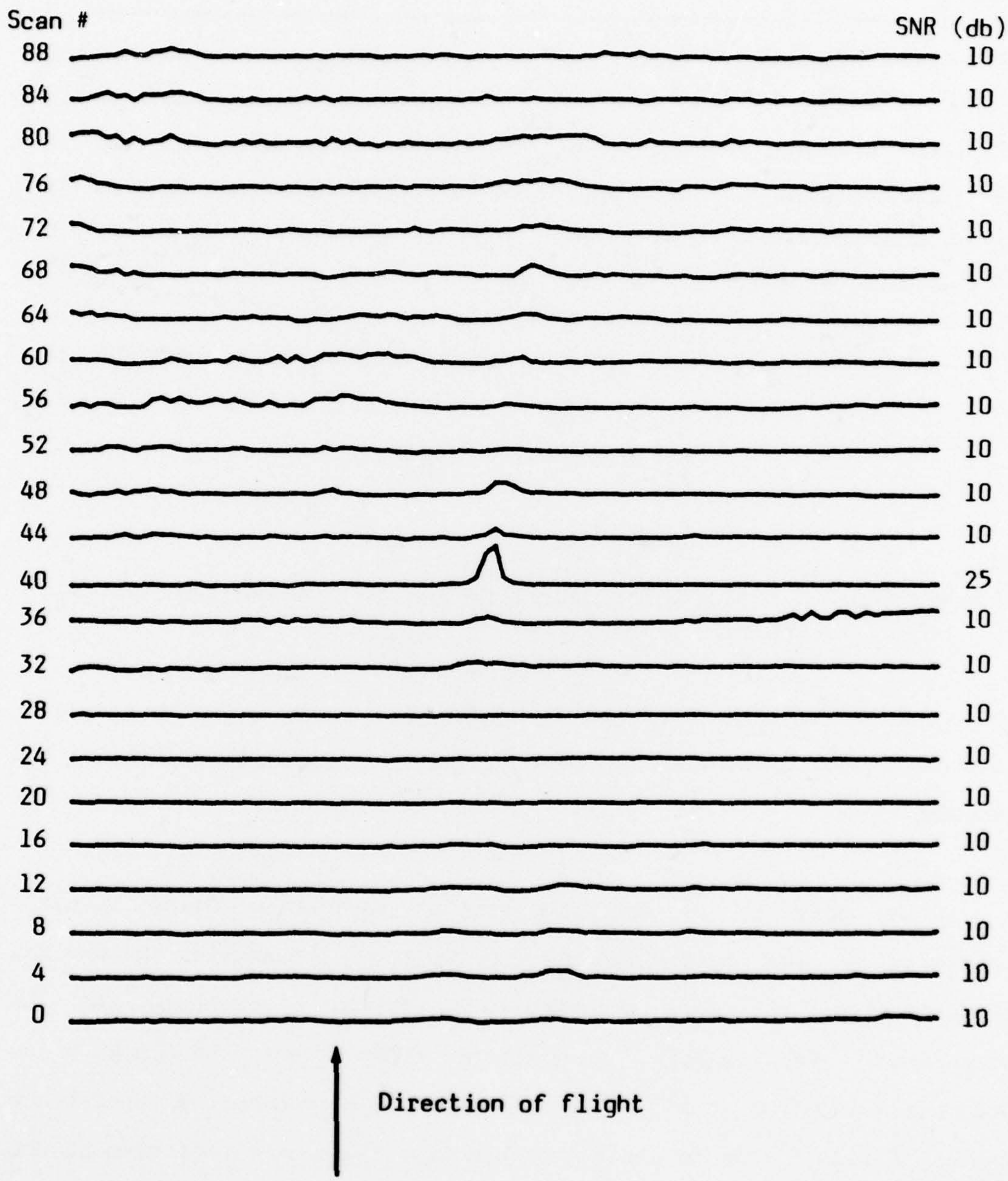


FIGURE 9(a) - One-dimensional correlograms for intersection reference (every fourth scan)

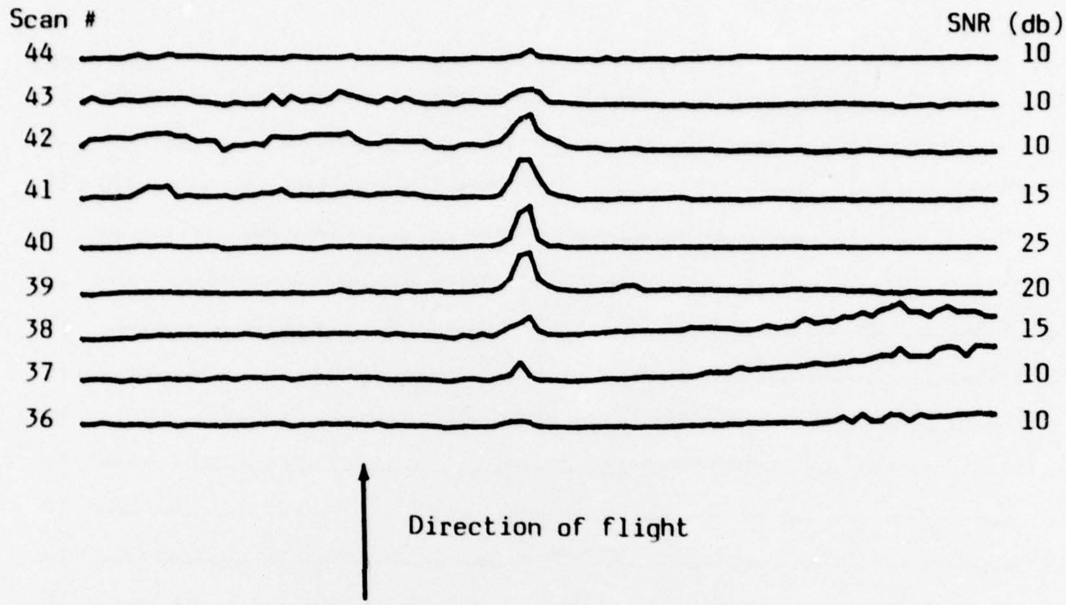


FIGURE 9(b) - One-dimensional correlograms for intersection reference (detail of (a))

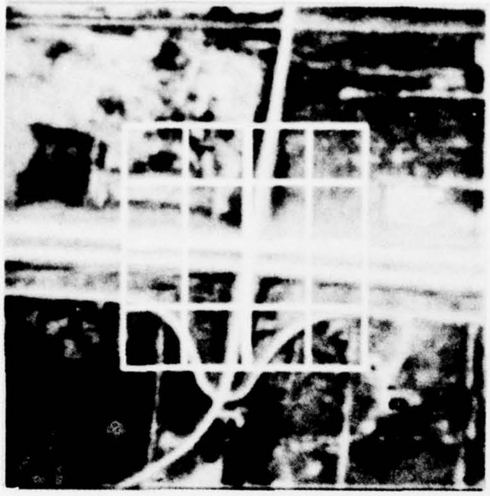
this points out the fact that the intersection was not a particularly good choice for a waypoint since it is too similar to other parts of the highway.

The accuracy of area correlation navigation fixes depends primarily on the resolution of the imagery. The smaller the picture element size, the more accurately a section of terrain can be pinpointed. For example, a platform with a drift of 0.8 km/h can accumulate an error of 133 m after 10 min. This requires a crosstrack sensor field of view to cover approximately 150 m on either side of the line of flight, for a total of 300 m in the crosstrack direction. A 100-element linear sensor covering the 300 m would provide a terrain resolution of 3 m per element.

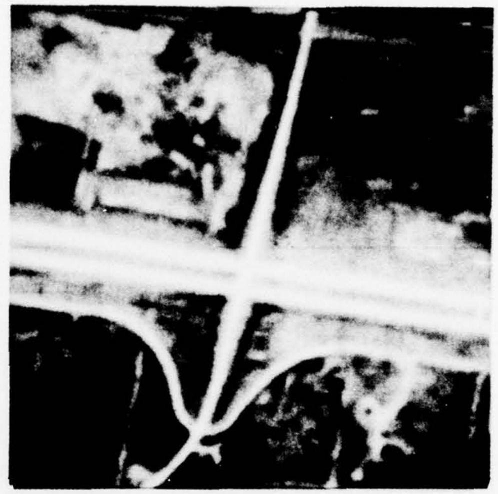
4.0 TERMINAL GUIDANCE

As the RPV approaches the target, the terminal phase is initiated. If the actual target is also prestored, it can be acquired in the same manner as for mid-course guidance. Otherwise, the data links between the RPV and the control station can be re-established and the operator can select the target. Either way, once the final target is locked on, the approach requires compensation for target image magnification. The technique of updating the target reference during range closure should be avoided if possible since accumulating errors can cause the system to wander off the target. A better method is to estimate the relative image magnification and use this value to control a zoom lens so as to maintain a constant target size in the field of view.

Reference 3 describes a technique for estimating not only relative translation and magnification between images, but also the relative rotation about the line of sight. Figures 10 and 11 demonstrate the technique applied to the highway photograph. In Figure 10(a), the target area is subdivided into a 4 X 4 array of subreferences each of 16 X 16 picture elements. The centers of these subreferences define a reference grid. The corresponding grid in the search scene is formed by locating each of the subreferences within the search scene. A least squares estimate of the coordinate transformation between the reference grid and the search grid provides the desired position, magnification and rotation data. In Figure 10(b), the search scene is a version of the reference that has been digitally translated by 2 picture elements vertically, 5 picture elements horizontally, magnified by a

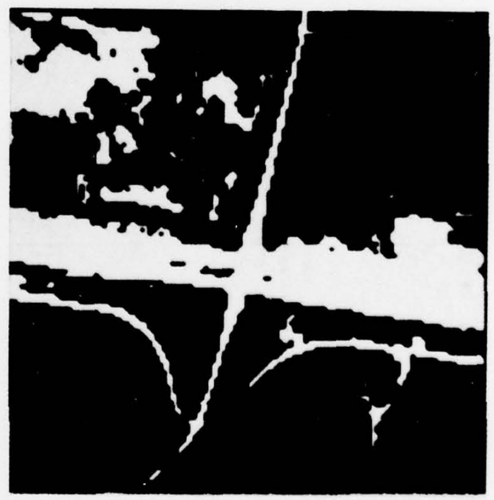


(a) Target reference



(b) Search scene

(c) Binary reference



(d) Binary search scene

FIGURE 10 - Highway reference and search scene

factor of 1.1 and rotated in the image plane by 5 degrees. Figures 10(c) and (d) are binary versions of (a) and (b) respectively.

Figure 11 shows the reference grid and the search grid obtained with the binary SSDA. Note that two upper right-hand search grid points are missing because their associated subreference images could not be uniquely found in the search scene. These subreferences did not contain sufficient picture detail to provide both x and y positioning.

The geometric relationship between the reference and search grids can be described by

$$\begin{bmatrix} u \\ v \end{bmatrix} = M \begin{bmatrix} \cos A & \sin A \\ -\sin A & \cos A \end{bmatrix} \begin{bmatrix} x-\Delta x \\ y-\Delta y \end{bmatrix} \qquad [2]$$

where (x,y) are reference grid locations, (u,v) are search grid locations, M is the unknown magnification, A is the unknown roll angle, and $(\Delta x, \Delta y)$ are the unknown translations. A least squares estimate of the unknown parameters, given x,y,u,v, is

$$A = \tan^{-1} \left[\frac{C_{uy} - C_{vx}}{C_{ux} + C_{vy}} \right] \qquad [3]$$

$$M = \frac{(C_{ux} + C_{vy})\cos A + (C_{uy} - C_{vx})\sin A}{C_{xx} + C_{yy}} \qquad [4]$$

$$\begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} = \begin{bmatrix} \bar{x} \\ \bar{y} \end{bmatrix} - \frac{1}{M} \begin{bmatrix} \cos A & \sin A \\ -\sin A & \cos A \end{bmatrix}^{-1} \begin{bmatrix} \bar{u} \\ \bar{v} \end{bmatrix} \qquad [5]$$

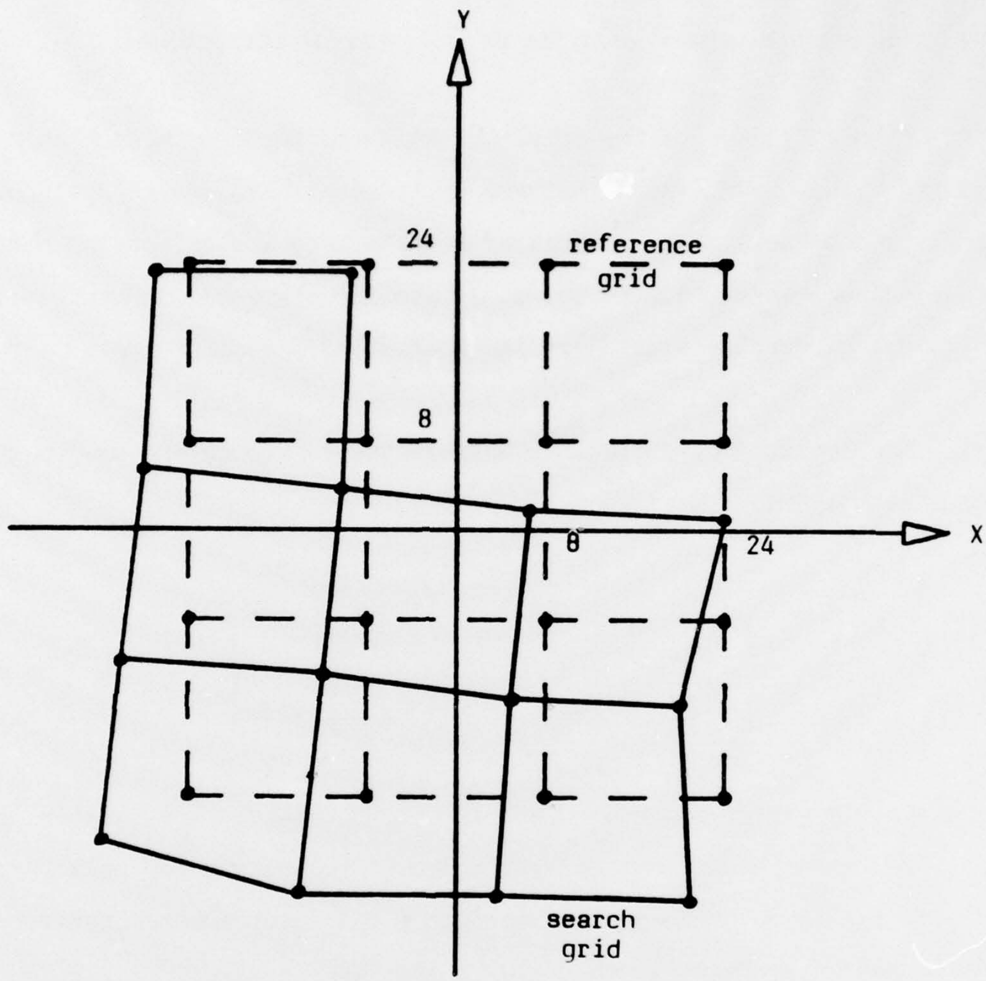


FIGURE 11 - Highway reference and search grids. The dots ● represent the locations of the center-points of the reference and search sub-images.

where $\bar{x},\bar{y},\bar{u},\bar{v}$ are mean values of the set of grid coordinates, and C_{ux} is the covariance of coordinates u and x; that is, $C_{ux} = \overline{(u - \bar{u})(x - \bar{x})}$, etc.

The exact transformation parameters for the example of Figure 10 are

Δx = 2 picture elements

Δy = 5 picture elements

M = 1.1

A = 5 degrees.

The estimated transformation, given by applying the grid data of Figure 11 to eq. [3] to [5], is

Δx = 2.320 picture elements

Δy = 5.128 picture elements

M = 1.093

A = 5.276 degrees.

These estimates are good enough to maintain continued tracking using the original target reference image.

In obtaining the search grid point locations, it is not necessary to perform a wide search for each subreference. Once the general location of the target is determined from a single wide search with a large reference (32 x 32, for example), the subreference locations may

be found with relatively small searches in the vicinity of the expected locations. The size of these subsearches is determined by the maximum expected relative magnification ratio and roll angle. For reasonable magnification and roll rates, these subsearches are considerably smaller than the search for the overall target position. Hence, computationally, the grid analysis algorithm does not add great expense to the basic area correlation algorithm.

This grid analysis technique has been extended to three dimensions for a moving target to account for rotations about perpendiculars to the line of sight (Ref. 3). This is a considerably more complex problem since it involves estimating the depth information of each grid point. Since sensor compensation for target rotation about perpendiculars to the line of sight is not possible, target reference updating is required. However it has been shown that the three-dimensional grid analysis leads to a much more accurate updating in the presence of three-axis rotation. No elaboration of this technique is given here because of its limited usefulness against fixed targets and its excessive cost for a long-range RPV mission.

5.0 CONCLUSION

The sequential similarity detection algorithm has been successfully applied (in simulation) to image-matching tasks involved in a long-range RPV attack mission. This brief study includes both the mid-course guidance of the RPV to the mission area and the terminal guidance in the weapon delivery.

The mid-course guidance consists of a set of navigation fixes by correlation with stored reference images at waypoints along a pre-programmed route. These navigation fixes provide precision updates to correct drift errors accumulated by the onboard navigation system. The simulation demonstrates that, for optimum performance, the waypoints should be judiciously chosen.

In the terminal guidance, a compensation for image magnification during range closure can be incorporated. Two-dimensional analyses of reference/search grid transformations enable the target tracker to maintain constant target size and orientation within its field of view by means of a zoom lens and roll gimbal. This allows an approach to the target without recourse to reference image updating.

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DREV R-4134/79 (UNCLASSIFIED)

Research and Development Branch, DND, Canada.
DREV, P.O. Box 880, Courcelette, Que. GOA 1RO

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Area correlation techniques are applied to the long-range remotely piloted vehicle (RPV) attack mission in both mid-course and terminal guidance phases. The mid-course guidance consists of a set of navigation fixes at waypoints along a preprogrammed route. The terminal guidance for weapon delivery incorporates a technique of compensation for magnification during range closure via a zoom lens. This report also presents simulations of both phases of guidance, using the sequential similarity detection algorithm as the image correlator. (U)

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On applique les techniques de la corrélation de surface au guidage en phases intermédiaire et terminale d'un avion sans pilote (télécommandé) effectuant une mission d'attaque. En phase intermédiaire, le cap est corrigé par la reconnaissance de points de référence échelonnés le long d'une route programmée à l'avance. En phase terminale, lors du bombardement, la cible est acquise par télécommande et la poursuite est effectuée de façon autonome au moyen d'une technique de compensation du grandissement apparent de la cible. Cette technique utilise un zoom.

Ce rapport porte également sur une simulation des deux phases du guidage et démontre comment un corrélateur d'image basé sur l'algorithme de détection séquentiel de similarité peut s'y appliquer. (NC)

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